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APPLICATION GUIDE FOR ELECTRICAL RELAYS FOR AC SYSTEMS

PART VIII VOLTAGE RELAYS

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Indian Standard
APPLICATION GUIDE FOR ELECTRICAL RELAYS FOR AC SYSTEMS
PART VIII VOLTAGE RELAYS

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APPLICATION GUIDE FOR ELECTRICAL RELAYS FOR AC SYSTEMS

PART VIII VOLTAGE RELAYS

0. FOREWORD

0.1 This Indian Standard (Part VIII) was adopted by the Indian Standards Institution on 19 October 1976, after the draft finalized by the Relays Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 Modern power systems are designed to provide uninterrupted electrical supply, yet the possibility of failure cannot be ruled out. The protective relays stand watch and in the event of failures, short-circuits or abnormal operating conditions help de-energize the unhealthy section of the power system and restrain interference with the remainder of it and thus limit damage to equipment and ensure safety of personnel. They are also used to indicate the type and location of failure so as to assess the effectiveness of the protective schemes.

0.3 The features which the protective relays should possess are:

a) reliability, that is, to ensure correct action even after long periods of inactivity and also to offer repeated operations under severe conditions;

b) selectivity, that is, to ensure that only the unhealthy part of the system is disconnected;

c) sensitivity, that is, detection of short-circuit or abnormal operating conditions;

d) speed to prevent or minimize damage and risk of instability of rotating plant; and

e) stability, that is, the ability to operate only under those conditions that call for its operation and to remain either passive or biased against operation under all other conditions.

0.4 Voltage relays have been used as protective devices for detection of faulty conditions in an ac system. In a faulty system the voltage becomes abnormal or unbalanced as a direct consequence. An overvoltage causes electrical overstress on the insulation of the apparatus while undervoltage may result in overload and thermal stress on insulation. These effects are cumulative in nature, hence time delayed induction type voltage relays have been frequently and successfully employed.

0.5 Voltage relays have been most widely used as auxiliary control function relays. They are mostly attracted armature instantaneous or short time delay relays. Their field of application is very diverse but technique is simple. Hence this guide is limited to the voltage relays for protective purposes only.

0.6 This guide is intended to assist the protection engineers in the application of voltage relays for protective use. However, it is emphasized that the object is neither to specify the relay to be used nor to suggest any particular protective system. The actual circuit conditions in an application may in all probability be different from those given in this guide. Hence the examples cited are to be regarded as mere illustrations to explain one or the other point pertinent to the conditions given in this guide.

0.7 In the preparation of this guide considerable assistance has been derived from several published books and technical papers and from manufacturers' trade literature.

0.8 This guide is one of the series of application guides for electrical relays for ac systems.

1. SCOPE

1.1 This guide (Part VIII) deals with the application of voltage relays covered by IS : 3231-1965*.

1.2 It does not cover application of voltage relays which are used as auxiliary relays for control or similar other purposes. It also does not cover the principles of system design and system protection.

2. TERMINOLOGY

2.0 For the purpose of this guide the definitions given in IS : 1885 (Part IX)-1966† and IS : 1885 (Part X)-1966‡ shall apply.

3. GENERAL FEATURES

3.1 The energizing quantity for a voltage relay is the rated frequency, alternating voltage (rms) of a magnitude appropriate to the relay setting and the intended application. Mostly, a single phase voltage input to a relay with single coil element is adequate.

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*Specification for electrical relays for power system protection.

†Electrotechnical vocabulary: Part IX Electrical relays.

‡Electrotechnical vocabulary: Part X Electrical power system protection.

3.1.1 There are however instances, when more than one voltage magnitudes differing in phase relationship derived from a three-phase ac system are supplied to a relay with polyphase elements. Examples are voltage relays for checking phase sequence between two systems and those employed for detecting single phasing conditions of a three-phase system.

3.2 Movement

3.2.1 Induction disc type relays are the most common forms of voltage relays used for protection. These are used as either overvoltage or undervoltage relays and are provided with adjustable time delay settings.

3.2.2 The attracted armature movement is frequently used for instantaneous overvoltage/undervoltage relays, which are used either with or without additional time-delay relays.

3.3 Classification

3.3.1 In protective applications, voltage relays are classified as follows:

a) Overvoltage relays,

b) Undervoltage relays, and

c) Combined (over and under) voltage relays.

3.3.2 An overvoltage relay is designed to perform its protective function when the rated frequency voltage applied to it increases to the operating value (an rms *magnitude*).

3.3.3 An undervoltage relay is designed to perform its protective function when the rated frequency voltage applied to it decreases to the operating value (an rms *magnitude*).

3.3.4 A combined (over and under) voltage relay develops its operating torque in a counter-clockwise or clockwise sense when the rated frequency voltage applied to it increases or decreases to the operating voltage of the relay respectively. It is calibrated on increasing voltages to close 'NO' contacts at tap settings and on decreasing voltages to close 'NO' contacts at lower percentages of the setting. The percentage may be fixed at 90 percent or higher or may be adjustable in the range of 30 to 60 or 60 to 90 percent.

4. CHARACTERISTICS

4.1 The voltage-time characteristics of induction time delay voltage relays are of inverse form. Typical characteristics are given in Fig. 1, 2 and 3.

4.2 Induction disc type voltage relays are generally provided with a number of taps and the range of tap settings is dependent on relevant application.

Attracted armature type voltage relays are provided with either fixed settings or tap settings or continuously variable settings depending on requirement/application.

Overvoltage relays are normally continuously rated for the relay tap voltage or the rated voltage at the respective taps. Undervoltage relays are normally designed to withstand at least 110 percent of relay rated voltage continuously at any tap setting.

4.3 Low Pick-Up Overvoltage Relays — A sensitive pick-up voltage characteristic with an operating range of 8 to 32 percent of rated voltage, usually with 4 taps in the range is available for overvoltage relays. At rated voltage of the relay the operating coil magnet is highly saturated to increase the impedance of the relay and to limit the current in the coil to a safe value. As the sensitive pick-up type overvoltage relays are likely to maloperate with any small input of third harmonic voltage likely to be present in power system, the relay coil circuit is series-tuned with a condenser to accept only the fundamental rated frequency voltage and to reject mostly any third harmonic voltage input.

4.4 Low Pick-Up Frequency Tuned Overvoltage Relays — A sensitive relay having a low pick-up value is normally used for detecting earthfaults in generators. As such a relay is likely to maloperate due to the presence of third harmonic voltage, the relay coil circuit is series-tuned and tuned shading coils are used so that the relay is sensitive to fundamental rated frequency voltage and the pick-up voltage on third harmonic is considerably high.

4.5 Frequency Compensated Relays — For overvoltage protection of generator, it is essential to ensure that the sensitivity does not change with frequency and it is necessary to employ frequency compensated relays. In induction disc type voltage relays frequency compensation is usually provided by selecting correct combination of coil reactance and resistance.

In order to get a uniform voltage-time characteristics over the compensated band of frequency, the relay is so designed that there is always a constant inductance to resistance ratio on each voltage setting tap. In case of instantaneous overvoltage relays, rectified ac operated relays having fairly uniform voltage-frequency characteristics are normally used.

NOTE — In certain applications, namely, capacitor control, overvoltage and undervoltage relays used in conjunction with separate time delay relays, etc, call for high resetting ratio so that the relay resets on recovery of voltage to normal limits.

5. CAUSES AND EFFECTS OF OVERVOLTAGES

5.1 Overvoltages occur due to the following causes:

a) An earth fault on system in which system neutral is not solidly earthed,

b) Sudden rejection of load by a fully loaded generator,

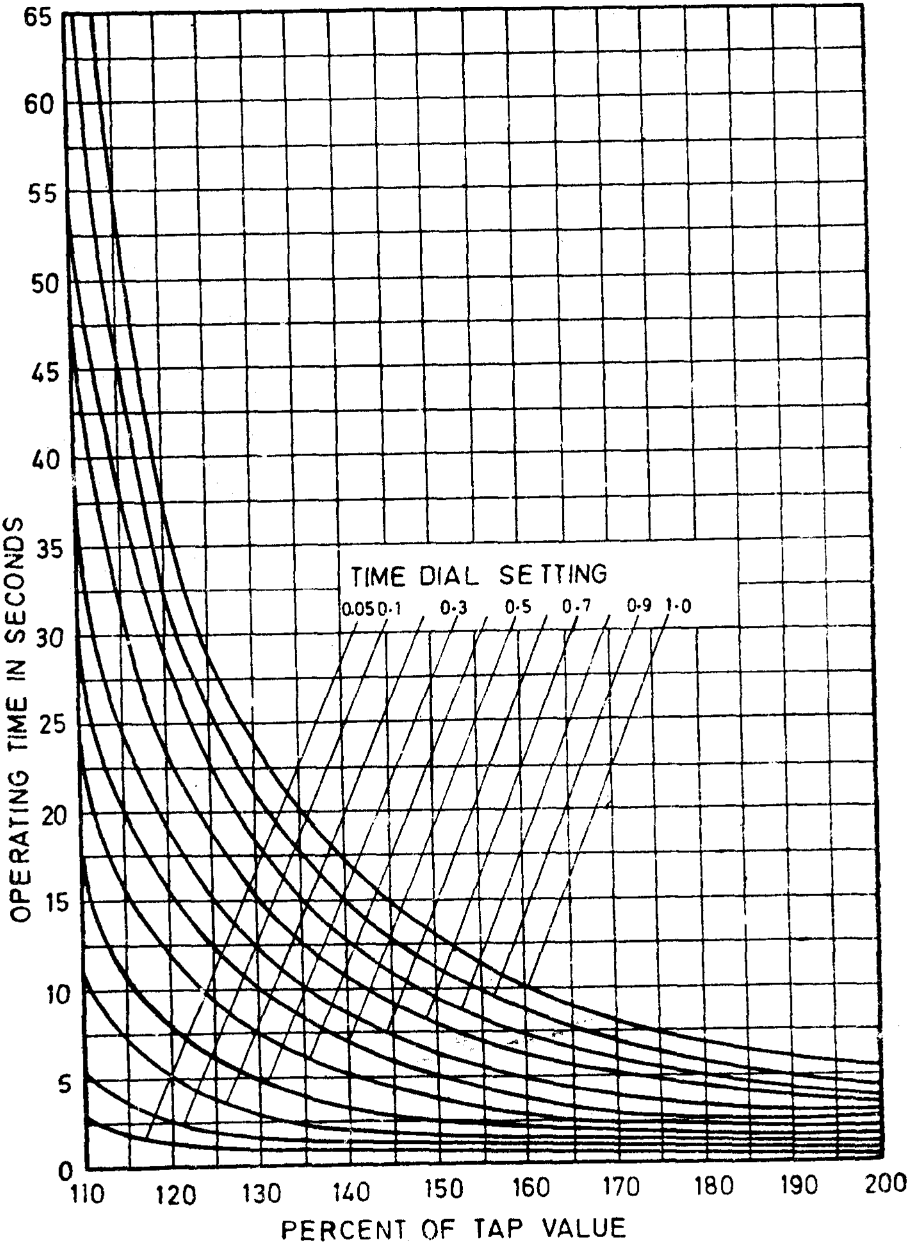


Fig. 1 A Typical Time-Voltage Curve of Overvoltage Relay

c) Switching inductive or capacitive circuits,

d) Re-striking of arc in circuit-breakers,

e) Induction in adjacent circuits caused by heavy current in a circuit,

f) Atmospheric disturbances on electrically exposed installations,

g) Long unloaded lines due to Ferranti effect, and

h) Supply disconnection of lightly loaded synchronous motor due to open circuit regulation.

5.1.1 Voltage relays may be used for protection against sustained overvoltages as are caused by **5.1** (a) and **5.1** (b). Overvoltages by the remaining causes are controlled and protected against, by techniques of equipment design, insulation co-ordination and application of protective devices, such as surge diverters and lightning arresters.

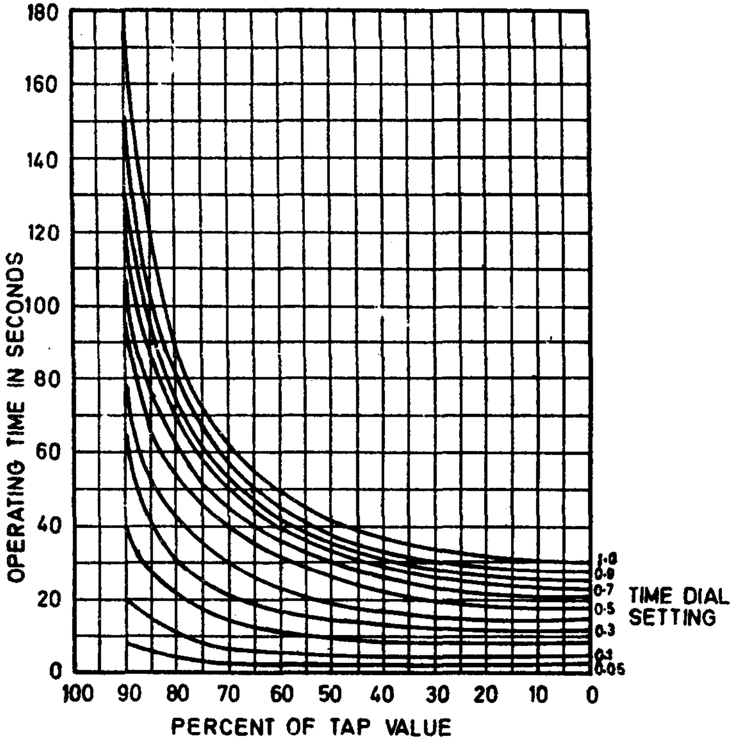


Fig. 2 A Typical Time-Voltage Curve of Undervoltage Relay

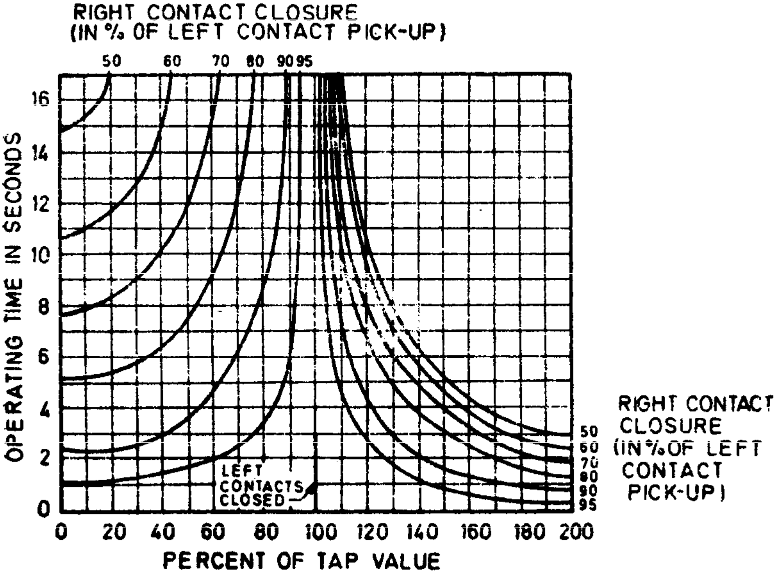


FIG. 3 A TYPICAL TIME-VOLTAGE CURVE OF COMBINED OVER AND UNDERVOLTAGE RELAY

5.1.2 Overvoltages cause high electric stress on the insulation of equipment which, if sustained for a long time, may lead to failure of insulation. In service, insulation may be subjected to abuse by overload, failure of cooling systems, growth of surface encrustation by external deposits which impede cooling, etc. One or more of these causes may aid insulation failure.

6. CAUSES AND EFFECTS OF UNDERVOLTAGE

6.1 Undervoltage occurs due to the following causes:

a) Fault on systems,

b) Shortage of reactive capacity in relation to excitation needs of the load,

c) Physical disconnection in varying manners,

d) Inordinately large voltage drops in the transmission and distribution network, and

e) Voltage drops caused by large starting current requirements of motors, arc furnaces, etc.

6.1.1 The effect of undervoltage on induction motor drives is to overload the motor, to cause higher temperature-rise and occasional burnt-out, to increase the slip of the motor, and to considerably reduce the starting and pull out torques.

6.1.1.1 If supply is momentarily interrupted to a synchronous motor, the motor is required to be first switched out, otherwise supply could reappear at the motor terminal when the motor induced emf is not in opposition.

7. APPLICATIONS

7.1 Overvoltage Relays

7.1.1 *Overvoltage on Water Wheel Generator*

7.1.1.1 When the load on a water wheel generator is suddenly rejected due to tripping of a breaker feeding the load bus or a loaded transmission line, the generator would overspeed and may attain about 160 percent rated speed in about 5 to 10 seconds and it would take additional 60 seconds or more for the speed governor action to return the generator to its rated speed. The automatic voltage regulator will quickly respond and reduce the generator excitation normally but, by chance the automatic voltage regulator may be defective and fail to function correctly or may be on hand control. Damaging overvoltage may then occur in the stator windings was induced ac voltage in the field windings is likely to cause failure of field insulation.

7.1.1.2 If the generator auxiliary motors are supplied from the generator terminals by suitable arrangements, with the overspeeding of the generator the motor pull out torque will decrease inversely with the square of the supply frequency. At the same time the load torques, namely, of the circulating pumps and cooling fans, etc, will increase with the square of the speed. During this critical period the auxiliary motors must not stop. Motors of auxiliary drives for hydro-electric generators are usually rated 10 percent over the driven loads to give satisfactory performance under ±10 percent variation in the terminal voltage. Yet it could be seen from Fig. 4 that the motors would get overloaded almost by 90 percent when the generator speed reaches 133 percent rated speed and the motors would pull out. Protective action must therefore be completed before the generator speed rises to 133 percent.

7.1.1.3 Water wheel generators are designed to withstand speed up to 2·0 times rated speed. Auxiliary motors can withstand some overvoltage without damage but the generator bus and the connected switchgear apparatus would not tolerate more than 10 percent voltage rise. The protective overvoltage relay must limit the overvoltage to 10 percent.

7.1.1.4 A simple overvoltage relay is employed which operates to drop a field reducing dc contactor thus introducing a resistance in the exciter or

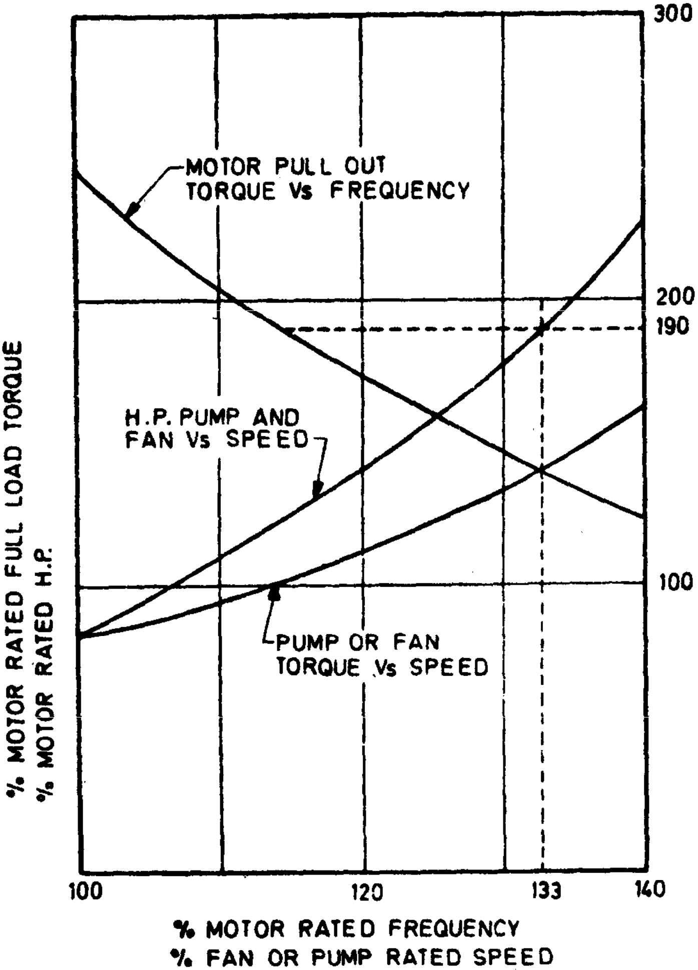


Fig. 4 Typical Motor Characteristics

field circuit and to project an alarm for operator to take necessary manual action (*see* Fig. 5).

7.1.1.5 To avoid consequent failures resulting from over-speed accompanied by overvoltages in a hydro-generator, frequency compensated overvoltage relays are used to trip the associated breakers. Generally a time delay overvoltage relay together with an instantaneous overvoltage relay is used. This time delay relay is usually set at 110 percent and the instantaneous relay at 130 to 140 percent. Typical trip circuit is shown in Fig. 6.

7.1.2 *Earth Fault in Generator Stator*

7.1.2.1 Operation of generators with isolated neutral is advantageous because of continuity of supply it provides on single earth faults and because it greatly limits the flow of line to earth fault currents, but is disadvantageous also because of overvoltages which result on the system and the difficulty of locating the earth faults. A balance is struck by earthing the generator neutral through a suitable current limiting impedance which may be a resistance, a reactance, a distribution transformer with resistance load or a potential transformer. With all earthing methods, the damage to the machine at the point of fault shall be weighed.

7.1.2.2 *Reactor earthing* — Generator installation which directly feeds 4-wire system should have reactor earthing to prevent overvoltage during line-to-earth faults which would damage loads connected from healthy phases to neutral wire. This method is desirable where generator installation directly feeds a cable network, particularly where old cables continue in service. The earth fault current is limited in this method to 25 to 100 percent of three-phase fault current.

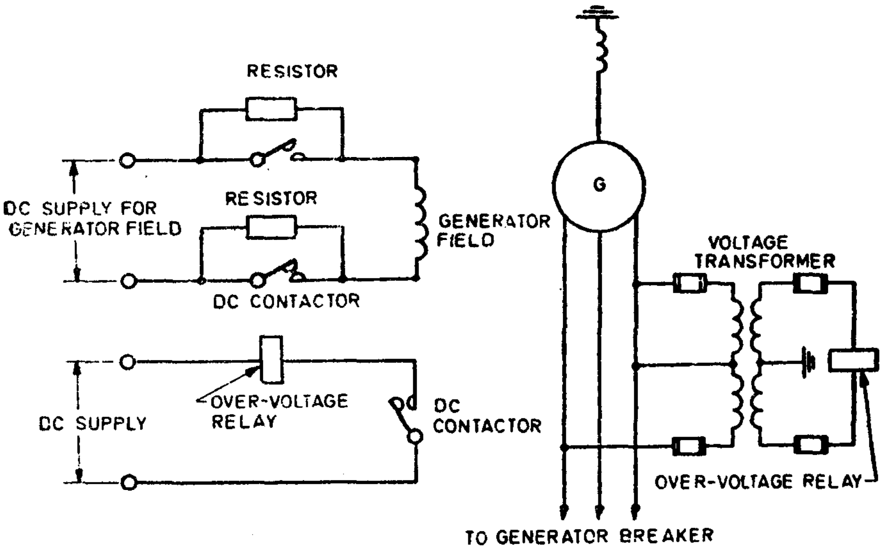
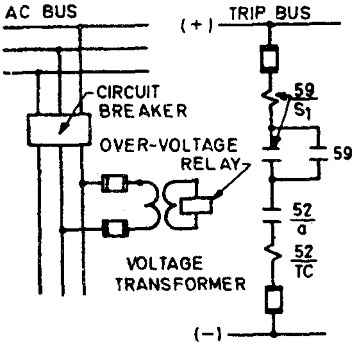


FIG. 5 GENERATOR OVERVOLTAGE PROTECTION



52 — Power circuit breaker
59 — Overvoltage relay
SI — Seal-in unit, with target
a — Auxiliary switch, closed when circuit breaker is closed
TC — Trip coil

FIG. 6 TYPICAL EXTERNAL CONNECTION USED FOR OVERVOLTAGE PROTECTION

7.1.2.3 Neutral resistor earthing usually does not permit use of earthed neutral arresters and hence installations most favourable to neutral resistance earthing are those having no direct lightning exposure but which require sufficient current for selective earth protection. The current range is 100 to 2 000 A.

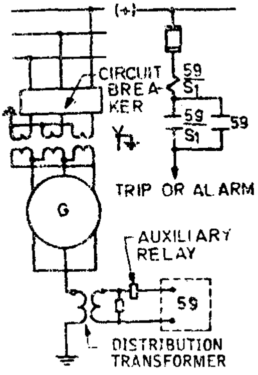
7.1.2.4 Distribution transformer with secondary resistor (*see* Fig. 7) which in effect is very high resistance earthing and where earth fault currents are limited to 5 to 15 A only are used in most cases with unit system installation. Appreciable earth fault current is not required because the voltage between the neutral and the earth can be comfortably used for relaying. No dangerous transient overvoltages are encountered if earthing equipment ratings are properly selected. Machine lightning arresters should be of the unearthed neutral type. Arresters should be used on the high voltage side of transformer to limit surges on the high voltage system.

7.1.2.5 The application of a potential transformer in a generator neutral produces a high reactance earthed system. The earth fault current is very low but high transient overvoltages are produced in switching at the generator voltage or from line-to-earth faults which result in arcing grounds. Line-to-neutral rated potential transformer from the point of core saturation should be used between the neutral of the generator and the earth to minimize a possibility of ferro-resonance oscillations between the capacitance to earth of the generator windings and the potential transformer reactance.

Line-to-neutral rated and line-to-earth connected potential transformer at the three-phase terminals of a generator is another variant of the method. In both cases, the generator and transformer must be connected directly together without interposing a breaker. It is also necessary to ensure that ferro-resonance will not occur. The method is similar to **7.1.2.4** but does not have its resistance damping characteristic which is desirable.

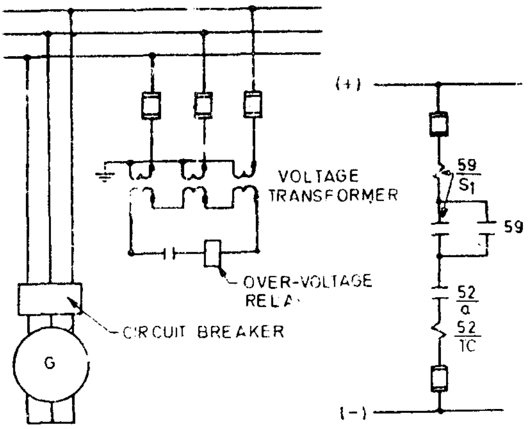
If, however, the generator is connected to the bus through a breaker at the generator voltage, the secondary side of the voltage transformer is loaded with a resistor to prevent transient overvoltages appearing due to restrikes in the breaker (*see* Fig. 8).

7.1.2.6 Earth fault in a generator stator occurs in the armature slots. The damage caused by such an earth fault is the burning of the winding insulation and burning of the stator iron, the extent of which depends on the magnitude of the fault current and the duration it sustains. The burning of insulation can be repaired by replacing the coil(s) in the faulted armature slot which needs a short outage of the generator for a few days. On the contrary burning of the stator iron caused by heavy fault currents or over extended time would require replacement of the burnt iron. This involves complete re-stacking of the iron and insertion and connection of the windings and the job may extend over several weeks. Besides, the loss of revenue would be enormous. The necessity of limiting earth fault to very low values and providing a selective earth fault protection is thus important and very much linked with the system of generator neutral earthing.



59 — Overvoltage relay
SI — Seal-in unit, with target

FIG. 7 TYPICAL EXTERNAL CONNECTION FOR PROTECTION OF AN AC ROTATING MACHINE



52 — Power circuit breaker
59 — Overvoltage relay
SI — Seal-in unit, with target
a — Auxiliary switch, closed when circuit breaker is closed
TC — Trip coil

FIG. 8 TYPICAL EXTERNAL CONNECTION USED FOR EARTH-FAULT PROTECTION OF A THREE-PHASE UNGROUNDED SYSTEM

7.1.2.7 If the earth fault current in a generator winding is sufficient to operate the generator differential protection, no other earth fault protection is required. In neutral reactor or interstar earthing transformer type systems, sufficient earth fault current would be available. When the neutral of a generator is earthed through high impedance to limit the earth fault current to low value (5 to 15 A), the differential protection would not adequately protect the generator. Earth fault protection, in such cases, is provided by voltage relays.

7.1.2.8 The following methods of voltage measurements are available:

a) Measurement of voltage between the generator neutral and the earth is made by a voltage relay if the generator neutral is grounded through a single phase voltage or distribution transformer, the secondary of which is loaded with a suitable resistor (*see* Fig. 7). The rating of the resistor may be selected as given in Appendix A.

b) Measurement of zero sequence voltage appearing across open delta connected secondary of a three-phase voltage transformer, the primaries of which are connected star and to the terminals of the generator and the neutral (primary) is tied to the earth (*see* Fig. 8).

7.1.2.9 Each phase of the generator windings generates a small magnitude of third harmonic voltage despite the distribution and chording which appears at the neutral. The magnitude depends on the generator design and increases from no load to full load. This voltage appears at the relay terminals from almost a negligible value to 2 to 3 V in normal service. The relay is series tuned to reject third harmonic voltage with a high factor (say 8) to the fundamental so that the lowest tap value could be selected. In practice the voltage tap selected should be about 2 V higher than the magnitude of the third harmonic voltage across the relay terminals.

7.1.2.10 In a unit type generator transformer system, a voltage may appear at the generator neutral when an earth fault occurs on the high voltage side of the transformer because of capacitive coupling between the high and low tension windings of the power transformer. The magnitude of this displacement voltage depends on the transformer inter-winding capacitance and the total zero sequence capacitance to earth of the generator side system. For the displacement voltage to be low, the generator side zero sequence capacitance to earth should have a low value. Secondly, if the high voltage side neutral of the power transformer is earthed solidly, the neutral displacement voltage on the generator side will be low. If the high voltage side neutral of the power transformer is earthed through high impedance the displacement voltage on the generator side will be large. The factors involved are varied and an easy assessment is not possible. Hence it is recommended that the time setting of the overvoltage relay should be appropriately chosen to avoid unwanted operation due to inter-winding capacitance effect.

7.1.2.11 An earth fault on the generator terminal produces a displacement voltage at the neutral equal to line to ground voltage available prior to the fault on the faulted phase. A fault in the generator winding would produce reduced displacement voltage until at neutral the displacement would be zero. The amount of winding towards the generator terminals protected by the voltage relay will therefore be,

$$\left\{ 100 - \frac{\sqrt{3} \times \text{Relay tap voltage} \times N}{V} \right\} \text{ percent}$$

where V = line to line voltage, and

N = voltage transformer ratio.

7.1.2.12 If a single-phase voltage transformer is used in place of the distribution transformer, the voltage relay is connected to project visual and audible alarm. Sometimes tripping is arranged through an auxiliary time delay relay.

NOTE — In some cases the neutral displacement voltage may be present for quite some time (for example, when the relay is used for alarm functions only) and its magnitude may exceed the continuous withstand capability of the relay. Proper measures should be taken in such cases to avoid damage to the relay. This can be achieved by connecting hand reset normally closed contact of the relay in series with the relay coil so that the coil is disconnected from the voltage circuit after operation of the relay.

7.1.3 *Protection of Parallel Transformer Feeder*

7.1.3.1 When parallel transformer feeders are connected to unearthed star or delta winding of transformers, an earthfault occurring on the feeders will not be cleared even with the operation of the feeder breaker because of infeed from the low voltage side. Such condition of earthfault remaining in otherwise insulated system will cause overstressing of the system and may precipitate further breakdown.

This condition is detected by connecting an overvoltage relay connected to the tertiary winding of a voltage transformer, positioned at the terminals of the delta or unearthed star winding of the transformer as shown in Fig. 9.

The relay so connected will operate for external as well as internal feeder fault. As such to provide discrimination the relay shall be time delayed.

7.1.4 *Protection of Shunt Capacitors*

7.1.4.1 Shunt capacitors are subjected to overvoltages due to either system voltage fluctuations or if the capacitors are used under light load conditions. As such overvoltages may exceed the withstand value of the capacitors, protection against such overvoltage condition is provided usually by an induction disc type overvoltage relay.

7.1.4.2 For large capacitor banks, detection of out of balance condition due to blown fuse in one or more number of units is done by a sensitive overvoltage relay similar to the one used for generator earthfault protection utilizing distribution transformer earthing. The relay connections for such protection are shown in Fig. 10A and 10B.

7.1.5 *Protection of Unloaded Lines* — In long transmission line, considerable overvoltage may occur under light load condition due to excess capacitive megavars on the system. Overvoltage may also occur at one end of the long line when the other end is open due to capacitance effect.

An overvoltage relay is used to monitor such a condition so that necessary corrective action, such as switching-in of shunt reactors or inter-tripping of other end can be taken.

7.1.6 *Protection of Synchronous Motors* — When a synchronous motor connected to bus with no other appreciable load is running on very light load or no load, a failure of supply will result in instantaneous overvoltage of the order of 20 to 30 percent due to the open circuit regulation of the machine. Instantaneous overvoltage relay is employed to provide protection during such conditions.

7.1.7 *Protection of Power Transformers*

7.1.7.1 Presence of sustained power frequency overvoltage is detrimental to the life of terminal equipment, the most important of them is power transformer.

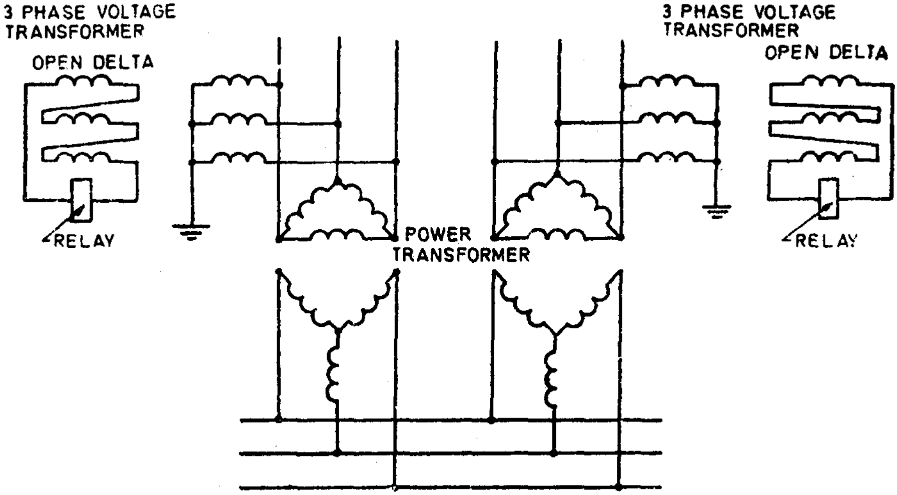


FIG. 9 PROTECTION OF PARALLEL TRANSFORMER FEEDER

7.1.7.2 Overvoltage causes a proportional increase in the working flux and disproportionately great increase in magnetizing currents. Under conditions of over-excitation a large component of flux is diverted to the steel structural parts from the highly saturated laminated core parts. This results in excessive heating of the core bolts, etc, and subsequently leads to failure of core bolt insulation and ultimately the failure of the transformer.

7.1.7.3 Reduction of frequency has an effect with regard to flux density similar to the overvoltage.

7.1.7.4 Hence operation of transformers on overvoltage beyond permissible limit and particularly under system low frequency condition must not be continued. Suitable relays which measure the ratio of voltage to frequency should be used to monitor such overfluxing condition and to initiate corrective action. Such relays should preferably be provided with time delay to avoid unwanted operation on momentary system disturbances.

7.2 Undervoltage Relays

7.2.1 *Undervoltage Protection of Motor Circuits*

7.2.1.1 Effects of undervoltage on motor loads are as follows:

a) Synchronous motors fully loaded at unity power factor may pull out of step below 75 percent rated voltage;

b) Induction motors loaded fully may stall if the supply voltage falls below 70 percent;

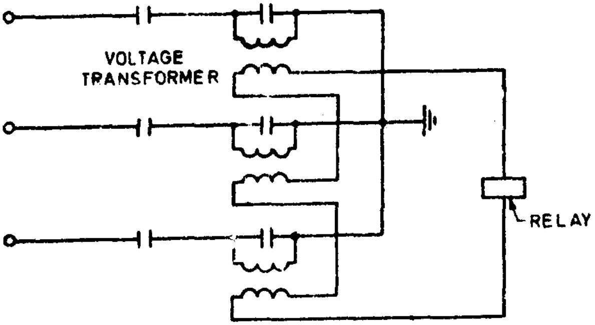
c) AC contactors may drop out and disconnect loads below 65 percent of the rated voltage;

d) Synchronous motors loaded at 0·8 power factor may pull out when voltage drops below 60 percent, however, lightly loaded motors may continue to remain in service;

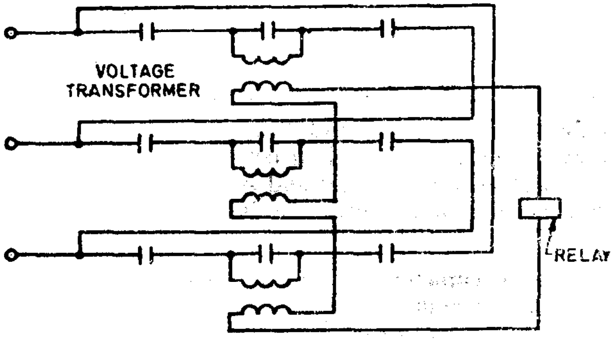
e) Momentary failure of supply is a particular case of undervoltage which may be serious to synchronous motors driving loads. As the supply reappears after failure, the motor internal emf may not be in phase opposition to the terminal voltage in which case the motor may fail to pull in step, it may oscillate and pull out; and

f) Single-phase supply is another particular case of undervoltage on three-phase supply systems, which causes overload on supply cables and thermal damage to insulation of windings or conductor burnt-out in the windings of motors driving loads.

7.2.1.2 To prevent starting and running at abnormally low voltages, synchronous motors should be provided with undervoltage protection



A Star Connected Bank



B Delta Connected Bank

FIG. 10 SHUNT CAPACITOR OUT OF BALANCE PROTECTION

preferably of inverse time characteristics. Similarly, induction motors may be provided with undervoltage protection against a three-phase drop in voltage. To prevent tripping during transient voltage dip, such relays are generally suitably time delayed and are connected either between phase to earth or between phase to phase.

7.2.2 *Undervoltage Relays for Auto Changeover Circuits*

7.2.2.1 When two independent supply sources are available and auto-changeover to healthy source from defective source is desired, undervoltage relays are used to monitor defective conditions, such as failure of supply, and sustained undervoltage.

If the bus is connected with motor load, care is taken to effect the auto-changeover only when the bus voltage due to the combination of induced emf of the motor subsides considerably, namely, 20 to 30 percent of rated voltage to avoid possible restoration of supply out of phase with the induced emf. In such case an additional undervoltage relay having an effective setting of 20 to 30 percent is employed.

7.2.3 *Undervoltage Protection of Shunt Capacitors/Synchronous Condensers* — Undervoltage protection is provided to disconnect the capacitor banks under low voltage conditions. This would prevent re-energizing the bus-bars to which partially discharged capacitors are connected, the capacitor voltage being unsynchronized with the supply system. The necessity for this depends on the time in which the capacitors discharge relative to the 'Dead Time' before the supply is restored. For this application a relay having high drop-out/pick-up ratio is used together with suitable time delay relay.

7.2.4 *Use of Undervoltage Relay as Phase Selectors in Distance Protection* — In switched distance relays, undervoltage relays are at times used as a phase selector to detect earthfaults and to switch-in appropriate quantities to the measuring units. Such undervoltage units usually having a setting of 80 to 85 percent nominal phase to neutral voltage are particularly suitable on resistance earthed systems where the earthfault current may be less than the load current.

7.3 *Combined Overvoltage and Undervoltage Relays*

7.3.1 Combined overvoltage and undervoltage relays can be used to switch-in or switch-out a shunt reactor connected to a line. In case of over-voltage, the respective unit operates and switches-in the reactor and in case of undervoltages, the undervoltage unit operates and switches-out the reactor.

7.3.2 When shunt capacitors are used to control the voltage, combined overvoltage and undervoltage relays can be used to monitor the condition and to perform capacitor control function.

7.3.3 Combined overvoltage and undervoltage relays can be used as a voltage regulating relay for tap changer control of transformers.

APPENDIX A

[*Clause* 7.1.2.8 (a)]

SELECTION OF SECONDARY RESISTOR

A-1. The secondary resistor is selected such that its kW loss during a line-to-earth fault is equal to the capacitative kVA to earth or the effective resistance in the machine neutral is one-third the zero sequence capacitative reactance. In calculating the capacitance to earth, important contribution is from machine winding capacitance, the surge protective capacitance and the low voltage cable connected to the voltage relay. The contribution of capacitance to earth of bus duct, lightning arresters and transformer low voltage winding is unimportant and is neglected. With a total three-phase capacitance to earth of generator, as stated above,

$$\text{The charging kVA} = \frac{2\pi f C \times V_1^2}{\sqrt{3} \times 10^3}$$

where

C = capacitance to earth in μF, and
V_1 = line to line voltage.

A-2. The distribution transformer primary voltage is normally selected from one of the standard ratings close to the generator line-to-line voltage. The secondary rating of 231 V is recommended to give good sensitivity for a 64 V rated voltage relay.

$$\text{The secondary resistance} = \frac{1}{N^2 \times 2\pi f C} \text{ ohms}$$

where

N = the turns ratio of the distribution transformer, and
C = capacitance to earth in μF.

$$\text{The current rating of the resistor} = \frac{V_1 N \, . \, 2\pi f C}{\sqrt{3}} \text{ A}$$

$$\text{The distribution transformer continuous rating} = \frac{V_1^2 \, 2\pi f C}{10^3} \text{ kVA}$$

A low pick-up overvoltage relay rated 64 V, with pick-up voltage taps 8 to 32 percent and operating time characteristic as given in Fig. 11 may be employed.

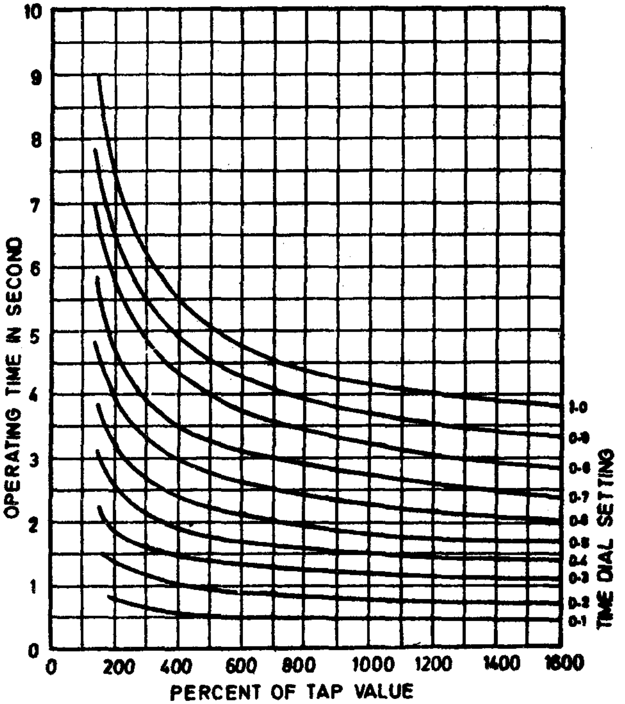


FIG. 11 A TYPICAL TIME-VOLTAGE CURVE OF LOW PICK-UP OVERVOLTAGE RELAY

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